Ramping Control Using a Spreadsheet

D. Y. Wang, R.P.Johnson*, L.S.B. Ng, W.J. Pearce
Brobeck Division of Maxwell Laboratories, Inc., 4905 Central Ave. Richmond, Ca. 94804
*Now at CEBAF,Newport News, Virginia

Abstract

The model 1.2-400 synchrotron light source built by Maxwell Laboratories for Lousiana State University uses a 200 MeV injector. After injection and accumulation, the beam is ramped up to 1.3 GeV in less than 30 seconds. During ramping, the dipole magnet waveform must be synchronized with those of 3 families of quadrupoles, 2 families of sextupole, 24 trims and the RF voltage. A commercially available spreadsheet program (20/20) incorporating lattice physics, magnet calibrations and flexible curve fitting was used to generate the necessary waveforms. These are downloaded to two list processors, auxiliary CAMAC crate controllers, which control the 31 DAC channels. The spreadsheet approach was cost effective in terms of programming effort, yet still enabled quick changes to the ramp path, allowed cycling of all magnets to standardize magnet settings and provided for easy graphical feedback. The implementation of the ramping spreadsheet and experience with its usage will be described.

I. Introduction

The MLI model 1.2-400 synchrotron light source has been described in detail elsewhere [1]. After beam is injected and accumulated, the beam energy is ramped up from 0.2 GeV to the flattop energy of 1.2-1.3 GeV in less than 30 seconds. During ramping, 31 control currents must be incremented in synchrony. In addition, at the end of a store after the beam is dumped, all magnets must be brought back to a standard state by cycling of the magnet currents. Given these requirements, a convenient method of generating and modifying these control current waveforms was essential for commissioning.

The user interface chosen was a spreadsheet program, 20/20, produced by Access Technology, Inc. This spreadsheet ran on a Vax Station under Decwindows. The spreadsheet format is well-suited for generating the large number of points which make up magnet waveforms during ramping. The logic of the calculations is linear, progressing from input to output without any branching. Moreover, the interface is user friendly. A "mouse" enables rapid paging through data and entry of values into selected cells. Lastly, graphs of the magnet waveforms which are calculated or read back from ADC's are readily displayed for diagnostic purposes.

In section A, the spreadsheet design requirements are discussed. In section B, the spreadsheet structure is described, showing how a configuration of the synchrotron is defined. Section C contains a brief recount of the operating experience..

B. Spreadsheet Design Requirements

The organization of the ramping spreadsheet is driven principally by two considerations.

The most important consideration for the spreadsheet design was governed by the requirement of providing enough flexibility so that quite general ramping waveforms could be generated with minimal user input. The user only needs to enter a small number of configurations at different energies along the ramp which has been found by experience or theory.

Subsequent automatic calculations join these configurations and divide the waveforms into many fine steps. To do this, each configuration is associated with a time up the ramp and also a "slope". This "slope" value is actually the desired tangent of the curve at that time normalized to the slope of a straight line connecting two configurations and varies between 0 and 1. A cubic fit is then used to join between configurations; it allows four

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degrees of freedom which enables the values and slopes to be matched.

A ramp cycle for the dipole current is shown in figure 1 to illustrate the curve fit. The smooth transitions at the beginning and top of the ramp, obtained by specifying zero slopes, minimize beam losses that may occur due to eddy current induced effects. In this illustration, the flattop time is only about 5 seconds. During operation, the ramp waveform is actually halted at flattop and reinitiated only when a dump is desired, allowing beam to be stored for as long as the beam lifetime.

After beam is dumped, the ramp waveform takes all magnet control currents down to zero and brings it up to the injection level. This was the standardization cycle used.

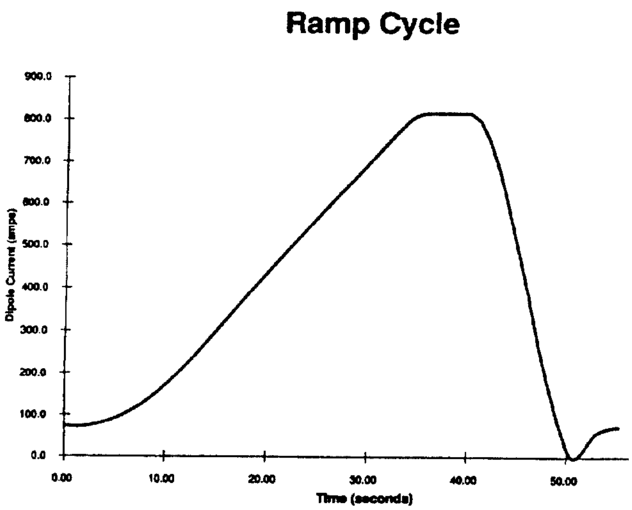

Fig. 1

The other major consideration in the spreadsheet design was that a machine configuration must be easily understood in terms of lattice parameters such as beam energy, betatron tunes or chromaticities. A machine configuration is completely defined by the set of 31 set-points for 30 magnets and RF voltage at a particular time.

But the representation of a particular magnet set-point is not unique. For example, the settings of the focusing and defocusing quadrupoles in the lattice can be shown as currents in units of amperes or alternatively they can be defined completely by the betatron tune values.

Using the latter representation assumes a much more detailed knowledge of the machine. As a first step, one needs the beam energy and quadrupole gradients in term of dipole current and quadrupole current settings. This come from previously measured calibration curves. Then it must be assumed that the synchrotron behaves sufficiently closely to the ideal lattice that a quadrupole perturbation is linearly related to a change in tune. The calibration curves may have errors and the synchrotron may not behave like the ideal lattice. But the utility of this representation, which was the one chosen for entering values into the spreadsheet, is that ideally, various parameters remain constant independent of beam energy up the ramp. Deviations point to anomalies.

C. Spreadsheet structure:

The spreadsheet structure is illustrated in figure 2 which shows only the top left corners of each section of the spreadsheet. As discussed in section B, configurations are entered into the Lattice Parameters Representation. In this representation, the variables are the beam energy, betatron tunes, chromaticities, and orbit correction deflection angles. These define the currents of the dipole, the focusing and defocusing quadrupole families, the focusing and defocusing sextupoles, and all trims which form the "Currents Representation". (The current waveform for the achromatic quadrupole family is scaled directly to the beam energy.)

Only 15 machine configurations are entered for the entire ramp cycle. After the curve fitting process, 141 expanded configurations in currents are generated. By use of power supply calibrations, these are converted into DAC settings. At this stage, timing offsets between the various magnets can be introduced. These offsets account for the different time lags in various power supplies.

A custom macro outputs this file to disk. A stand-alone program further expands the 141 configurations into 15000 configurations by linear interpolation. The final ramp waveform has this many fine steps. When each step is advanced, a momentary tune error can occur since magnet currents are updated with small relative delays, but no larger than 20 microseconds. With so many steps, the largest tune deviation is limited to 0.002. The final ramp waveform is loaded into list processors. These are CAMAC crate-controllers which load the data into appropriate devices when triggered.

Lattice Parameters Representation

Time(s)	E(GeV)	tunex	tuney
0.00	0.11	3.260	1.168
2.00	0.11	3.260	1.168
5.00	0.14	3.260	1.168

Currents Representation

slope	time	Ibm(A)	Iqf	Iqd
0.00	0.00	72.5	21.5	16.5
1.00	2.00	72.5	21.5	16.5
1.00	5.00	92.1	27.3	21.0

Expanded Configurations (currents)

time	Ibm(A)	Iqf	Iqd
2	72.5	21.5	16.5
2.3	73.7	21.8	16.8
2.6	75.1	22.2	17.1
2.9	76.6	22.7	17.4

Expanded Configurations (DAC counts)

	time	Ibm(A)	Iqf	Iqd
offset(ms)		60	66	77
	200	3912	4221	4272
	230	3979	4292	4344
	260	4053	4371	4424
	290	4135	4458	4513

Figure 2 Spreadsheet Structure

D. Operational Experience

The spreadsheet ramping program has been used extensively to generate different ramp cycles during the commissioning of the MLI model 1.2-400.

During the first successful ramp only a few microamperes survived at 1.2 GeV out of an accumulated current of a few milliamps. Subsequently the ramping efficiency has improved dramatically. For example, out of 200 mA accumulated, more than 90% survives up the ramp. This was mainly the result of better vacuum.

The first successful ramps were done by directly scaling all other magnet currents with respect to the dipole current. The intentional timing offsets used to compensate for the time lag between power supplies proved to cause large beam losses and were deleted. For ramping up to 1.4 GeV, the dipole calibrations which show saturation behaviour at energies above 1.3 GeV had to be incorporated.

The betatron tunes are constant up the ramp in the spreadsheet. But measurements using a network analyzer show that the horizontal tune moved over a range of ± 0.05 during ramping. In any case, the optimum tunes in the spreadsheet were (3.203, 1.453) versus (3.260, 1.168) for the theoretical lattice.

These discrepancies were mainly due to problems with the calibrations of the power supplies which drifted after the initial tests. It was not surprising that the spreadsheet structure was soon augmented with a section which transformed a configuration in the currents representation, found by trial and error, into the lattice parameters representation.

In terms of the original design, the most successful feature was the use of the standardization cycle shown in figure 1. It has to be run if beam is to be accumulated at injection energy.

Summary:

Despite all the problems encountered during operation, the spreadsheet interface for ramping control is still to be recommended. Indeed, its flexibility is proven by how readily changes were made to handle the problems encountered. The graphical interface was very useful in the debugging phases. But most importantly, for a cost of about $1K plus 100 hours of initial programming effort, there is no other platform that can provide this degree of ramping control.

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